The Isothermal Dendritic Growth Experiment (IDGE)

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Dendrites describe the tree-like crystal morphology commonly assumed in many material systems -particularly in metals and alloys that freeze from supercooled or supersaturated melts. There remains
a high level of engineering interest in dendritic solidification because of the role of dendrites in the
determination of cast alloy microstructures. Microstructure plays a key role in determining the
physical properties of cast or welded products. In addition, dendritic solidification provides an
example of non-equilibrium physics and one of the simplest non-trivial examples of dynamic pattern
formation, where an amorphous melt, under simple starting conditions, evolves into a complex
ramified microstructure.

Although it is well-known that dendritic growth is controlled by the transport of latent heat from the moving solid-melt interface as the dendrite advances into a supercooled melt, an accurate and predictive model has not been developed.

Current theories consider: 1) the transfer of heat or solute from the solid-liquid interface into the melt; and, 2) the interfacial crystal growth and growth selection physics for the interface. However, the effects of gravity-induced convection on the transfer of heat from the interface prevent either element from being adequately tested solely under terrestrial conditions.

The Isothermal Dendritic Growth Experiment (IDGE) constituted a series of three NASA-supported microgravity experiments, all of which flew aboard the Space Shuttle *Columbia*. This experimental space flight series was designed and operated to grow and record dendrite solidification in the absence of gravity-induced convective heat transfer, and thereby produce a wealth of benchmark-quality data for testing solidification scaling laws.

The first flight of the IDGE flight, on STS-62, took place in March 1994, on the Second United States Microgravity Payload (USMP-2), with a second flight on STS-75, in February/March 1996, on the Third United States Microgravity Payload (USMP-3). Both flights used ultra-pure succinonitrile (SCN) as the test material. SCN is an organic crystal that forms dendrites similar to the BCC metals when it solidifies. Thus, SCN provides a nearly ideal physical model for ferrous metals. The third and final IDGE flight, on the Fourth United States Microgravity Payload (USMP-4) mission, launched on STS-87 in December and March 1997, employed a different test material. This flight used pivalic acid (PVA), an FCC organic crystal that solidifies like many non-ferrous metals. PVA, like SCN, has convenient properties for conducting benchmark experiments. However, unlike SCN, PVA exhibits a large anisotropy of its solid-melt interfacial energy, which is a key parameter in the selection of dendritic operating states.

The data and analysis performed on the dendritic growth speed and tip size in SCN demonstrates that although the theory yields predictions that are reasonably in agreement with experiment, there are significant discrepancies. However, some of these discrepancies can be explained by accurately describing the diffusion of heat. The key finding involves recognition that the actual three-dimensional shape of dendrites includes time-dependent side-branching and a tip region that is not a paraboloid of revolution. Thus, the role of heat transfer in dendritic growth is validated, with the caveat that a more realistic model of the dendrite than a paraboloid is needed to account for heat flow in an experimentally observed dendrite. We are currently conducting additional analysis to further confirm and demonstrate these conclusions.

The data and analyses for the growth selection physics remain much less definitive. From the first flight, the data indicated that the selection parameter, s^* , is not exactly a constant, but exhibits a slight dependence on the supercooling. Additional data from the second flight are being examined to investigate the selection of a unique dendrite speed, tip size, and shape.

The data and subsequent analysis from the final flight experiment are currently at a preliminary stage, based on images received using telemetry from space. We compared the dendritic growth speed of PVA as a function of the supercooling to both terrestrially measured PVA data, and an estimate scaled from prior SCN microgravity data. The preliminary results of these tests indicate that the PVA data are in good agreement with the SCN data. This implies that dendritic growth in PVA is, like SCN, diffusion-limited, with little, if any, kinetic response. This observation conflicts with the conclusion reached by other investigators that there are large interfacial kinetic effects in PVA. Currently, we are extracting more accurate velocity and tip radius, shape, and side-branching measurements from post-flight 35 mm film and videos.

In addition to our investigation of dendritic solidification kinetics and morphology, the IDGE has been part of the development of remote, university-based teleoperations. These teleoperation tests point the way to the future of microgravity science operations on the International Space Station (ISS). NASA Headquarters and the Telescience Support Center (TSC) at NASA Lewis Research Center set a goal for developing the experience and expertise to set up remote, non-NASA locations from which to control Space Station experiments. Recent IDGE Space Shuttle flights provide proof-of-concept and tests of remote space flight teleoperations.

The IDGE flight series is now complete. We are currently completing analyses and moving towards final data archiving. It is gratifying to see that the IDGE published results and archived data sets are being used actively by other scientists and engineers. In addition, we are also pleased to report that the techniques and IDGE hardware system that the authors developed with NASA are being currently employed on both designated flight experiments, like EDSE, and on flight definition experiments, like TDSE.